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ABSTRACT

An intelligent tutoring system (ITS) must: (1) represent the relevant knowledge domain; (2) represent the student's state of knowledge of the subject matter; (3) represent an expert tutor; and (4) communicate with the student. Such systems reflect a cognitive orientation or information structure oriented (ISO) approach to instructional design. In this framework, instruction involves creating environments in which students are encouraged to construct and modify their own models of the world. The distinguishing characteristic of intelligent tutoring systems is their generative capability, i.e., their capability to construct a model of the student's unique construction of the subject matter and to generate the instructional interactions that will improve the student's model. A review of nine intelligent tutoring systems developed for a military instruction indicates that: (1) since none of the systems contain the four basic elements of an intelligent tutoring system, there are no true intelligent tutoring systems; (2) systematic research and development to determine whether intelligent tutoring systems teach or how they teach is absent; (3) the development of ITS to date has lacked adequate empirical study and scholarship; and (4) intelligent tutoring systems remain the most promising area available for achieving a breakthrough in instruction. (28 references) (GL)

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Artificial Intelligence in Education and Training: The Promise and the Reality

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ABSTRACT

A review of intelligent tutoring systems developed for military instruction is summarized. Nine systems are identified and discussed. Additionally, some personal impressions of development in the field are listed. These impressions, if substantiated, suggest that some fundamental changes in our approach to intelligent tutoring systems may be in order.

INTRODUCTION

This presentation is intended to provide some background and perspective for the more substantive presentations that follow. My comments focus on education and training in the United States military. This focus seems reasonable since military instruction is an area with which I am reasonably familiar, and it is the source of most of the research and development funding that has been provided for the topic area.

Intelligent tutoring systems is one of the terms generally used to describe products from this field of development and I will use it loosely here to refer to all attempts to apply artificial intelligence to instruction. Loosely, then, an intelligent tutoring system embodies an attempt to apply information structure oriented (ISO) approaches to the processes of instruction. Carbonell (1970) contrasted these ISO approaches with ad hoc frame-oriented (AFO) approaches based on programmed instruction techniques such as intrinsic programming (Crowder, 1959), which is the common approach seen in most programmed textbooks and in much computer assisted instruction. AFO approaches depend on pre-programmed blocks of static material usually called frames. These frames consist of text and/or graphic material followed by questions. Associated with the questions are pre-specified correct and incorrect answers which are matched with students' responses. The student has no opportunity to ask questions unless they exactly match pre-specified query options provided by the program designer.

The ISO approach is based on a well defined knowledge base of information about the subject matter. A separate, tutorial program operates on the knowledge base in order to generate instructional material, including questions and the answers to them, and, significantly, to respond to inquiries initiated by students. Discussions concerning the subject matter can, then, be initiated either by the computer program or by the student. This capability for mixed initiative is characteristic of intelligent tutoring systems. The approach is generative in that it depends on the generation of material from the knowledge base rather than on pre-programmed material and pre-stored, anticipated student responses.

In order to accomplish these objectives an intelligent tutoring system must include four capabilities:

1. It must represent the relevant knowledge domain. To some extent, it must contain the knowledge and understanding of a subject matter expert. In fact, it may serve as the goal state of knowledge to which students should aspire. However, intelligent tutoring system knowledge bases may differ from those typically used in 'expert systems' since they must support explanations of their operations, e.g., problem solutions, in ways that can be both understood and emulated by students at levels commensurate with their knowledge and mastery of the subject matter. Power and speed are emphasized in other artificial intelligence systems; explanation is at a premium in intelligent tutoring systems.

2. It must represent the student's state of knowledge, or model, of the subject matter. This model involves more than just tracking a student's progress up a monotonic learning curve. In order to generate appropriate material for the student, it must also be diagnostic. For example, it can match the student's actions with those that would be expected of an expert and from this "overlay" infer what in the knowledge base the student has learned, what has yet to be learned, and what misconceptions the student may have formed about the subject matter.

3. It must represent an expert tutor. The knowledge base represents the goal state for the learner, and the student model represents the current state of the learner. The system needs a way to transition the student from one state to the other. In other words, it needs some means to bring about learning. Tutorial expertise is expected to provide these means.

4. It must communicate with the student. If the tutorial dialogue is to be initiated on occasion by the student and if the intelligent tutoring system must provide understandable explanations generated from its knowledge bases, the user interface may not play the ancillary role it is usually relegated to in non-intelligent tutoring systems. As one recent commentator has noted, it may be the driving force of the system design (Wenger, 1987).

Support for most research and development is based on a perceived match of technology 'push' (or technological opportunity) with requirements 'pull'. The development of intelligent tutoring systems is no exception. The technology push can certainly be seen in the computational techniques that have been developed for artificial intelligence. Whether these techniques have achieved the well marketed goals of artificial intelligence and whether they represent the best way to do so remain moot, but the computational capabilities that have emerged are genuine and relevant.

The requirements pull seems well founded on the long range plans developed by each of the military services that describe a future in which military units are smaller, more decentralized, and dispersed -- far from military schools, subject matter expertise, training devices, and instructional expertise. These soon to be missing ingredients may be resupplied if they can be captured in portable computer technology. Even without the decentralization and dispersion suggested by our strategic planning documents, the need for subject matter and instructional expertise will only increase with the continued modernization of our military forces.

This match of technology push and requirements pull has certainly helped to motivate the development of intelligent tutoring capabilities and to create military research and development programs that have funded seminal systems such as SOPHIE, BUGGY, and GUIDON. However, intelligent tutoring systems development is not just an attempt to capitalize on artificial intelligence and apply it to the problems of instruction. It is also a product and expression of our times.

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Every instructional program, either explicitly or (usually) implicitly, embodies and tests a theory of human cognition. Intelligent training systems are no exception. They represent and instantiate a view of how people perceive, think, and learn. Intelligent training systems represent a view that is usually called 'cognitive.' They reflect a change in approach and emphasis from the fairly strict logical positivism of behaviorism to what we now call cognitive science.

Behavioral scientists have long debated what the fundamental phenomena of their study ought to be. Some have keyed on the first name of their science and have limited their research and theorizing to directly observable and measurable behavior. Others have been willing to extend their research and theories to the human consciousness -- human thought, memory, motivation, etc. -- underlying measurable behavior. The former prevailed roughly from the 1920s to the 1960s. The latter have come into their own since then.

The keynote of the cognitivists may have been struck by a single sentence in a seminal book, *Cognitive Psychology*, by Ulric Neisser who stated:

"The central assertion is that seeing, hearing, and remembering are all acts of *construction*, which may make more or less use of stimulus information depending on circumstances." (Neisser, 1967, p.10 -- the italics are Neisser's)

We have, then, developed the view that human cognition is an overwhelmingly constructive process. Recall is not viewed as the retrieval of items from memory, but as their reconstruction from more primitive cues. Perceivers and learners are not viewed as blank slates, passively recording bits of information transmitted to them over channels, but as active participants who use the fragmentary cues permitted them by their limited sensory receptors to construct, verify, and modify their own sensory simulations of the outside world.

This point of view calls into question the notion of instruction as straight-forward information transmission. What we are doing in instruction appears to be providing cues that learners use to construct models of the subject matter. We should not view instruction as transmitting information but as creating environments in which students are encouraged to construct and modify their own models of the world. The more directly and actively we can deal with students' models of the subject matter, the more effective our instruction may become.

We would like, therefore, to deal with students' models directly. We would like to identify missing information, correct misconceptions, determine what subject matter information the student used to build the model, respond appropriately to student requests for hints and explanations, know what information a student needs for the next stage of model development, and devise instructional interactions that are uniquely tailored for the student. These capabilities are not readily available from pre-specified instructional material, interactions, or sequences.

What we need is a generative capability -- a capability to generate a model of the student's unique construction of the subject matter and to generate the instructional interactions that will improve the student's model up to some prescribed threshold of validity or accuracy. This generative capability is a distinguishing characteristic of intelligent tutoring systems. That we choose to do this and assign to it a high priority is a product of the cognitive approach which in turn is well served by having its notions, models, and theories instantiated and tested in computer based instruction.

SOME MILITARY SYSTEMS

In 1975 (i.e., Fletcher, 1975a) it was possible to list all the intelligent tutoring systems (there were six) that were either developed or under development with a reasonable expectation that the list was comprehensive. Ten years later (Fletcher, 1985) it was reasonable to attempt a similar list although with less confidence that it was complete and with more uncertainty over which systems to include. The 1985 list included 16 systems.

Today any pretensions of completeness in such a list seem out of the question. An August 1988 search of ERIC for items concerned with artificial intelligence and either training or education or instruction referenced 451 articles. A candidate list of intelligent tutoring systems produced today would be out of date before it could be verified for accuracy.

Fortunately, this chapter focuses on intelligent tutoring systems in the military. If we limit our purview to intelligent tutoring systems that are (1) developed or being developed, (2) sponsored by the military, and (3) intended for applications in military training, we can devise a list with at least moderate pretensions to completeness. Those who wish to cast a broader net may want to peruse Wenger's (1987) excellent overview of intelligent tutoring systems.

The resulting list of military systems is presented in Table 1, roughly in chronological order of development. Nine systems met the three criteria listed above. They are described and discussed in more detail by Fletcher (1988).

SOME OBSERVATIONS

Seven observations on these systems are summarized in the following comments:

1. All these systems, except CBMS, simulate a device in order to teach students how to operate it (roughly, STEAMER, TRIO, SATS, and INCOFT) or maintain it (roughly, SOPHIE, IMTS, QUEST, and MACH-III). This approach implies both a preference in choice of subject matter and a preference in choice of instructional approach. These preferences may indicate consensual wisdom about the best use of intelligent tutoring systems for military applications. Subject matters involving device oriented maintenance and operator training and the tutorial approach of tutorial simulation may be at least good, and perhaps the best choices for intelligent tutoring systems used in military training.

The intelligent tutoring systems developed or under development before SOPHIE appear to have been Carbonell's SCHOLAR (Carbonell, 1970), Collins' WHY (Stevens, Collins, and Goldin, 1982), Feurzeig's MENTOR (Feurzeig, Munter, Swets, and Breen, 1964), Suppes' EXCHECK (Suppes, 1981), and Kimball's INTEGRATE (Kimball, 1973). None of these systems involved device oriented tutorial simulation. Device oriented simulation appears to be a particular emphasis of intelligent tutoring systems developed for military instruction, and it was a significant new direction contributed by the SOPHIE project.

2. All of these intelligent tutoring systems rely heavily on qualitative, rather than quantitative models of cognition. Use of these models contrasts with earlier approaches to computer assisted instruction. Some of the deepest roots in the development of computer assisted instruction are in mathematical psychology. An early objective for computers used in instruction was to combine mathematical, or quantitative models of cognition with control theory to produce genuinely optimal sequences of systematically individualized instruction (cf. Atkinson, 1972; Fletcher, 1975b). After a shaky start, these approaches began to deliver on their promise. However, this line of development

Table 1. Intelligent Tutoring Systems in the Military

System	Subject Matter	Sponsor	Reference
SOPHIE	Electronic Maintenance	Tri-Service & DARPA	Brown, Burton, & DeKleer (1982)
STEAMER	Steamship Propulsion	Navy	Hollan, Hutchins, & Weitzman (1984)
IMTS	Helicopter Blade-fold Maintenance	Navy	Towne & Munro (1988)
CBMS	Memorization of Hierarchical Concepts	Navy & Army	Half (1986)
TRIO	Radar Intercept Tactics	Navy	Feurzeig, Ash, & Ricard (1984)
QUEST	Electronic Troubleshooting and Operation	Navy & Army	White & Frederiksen (1985)
SATS	Radar Signal Analysis	Air Force	Melvin (1986)
MACH-III	HAWK Missile Maintenance	Army	Massey, de Bruin, & Roberts (1988)
INCOFT	PATRIOT Missile Engagement Control	Army	Feurzeig, Massey, Downes-Martin, & Ritter (1986)

seems to have been swept aside by the cognitive revolution which was far more concerned with asking interesting questions than with finding well understood (i.e. quantitative) answers. It is not surprising that qualitative models and the development of instructional approaches based on them is a hallmark of intelligent tutoring systems equally prevalent in education and training applications.

Clancey (1986) has characterized qualitative modeling as definitional for expert systems and artificial intelligence:

"What is an expert system? A simple answer can be given, one that is half-known and has been half stated by many people: Expert systems contain qualitative models of the world, in contrast with quantitative models ... Describing AI as 'non-numeric science and engineering' is more to the point: Artificial Intelligence is the study of computational techniques for acquiring, representing, and using qualitative models of physical, perceptual, cognitive, and social systems." (p. 1, the italics are Clancey's)

3. If we list the three system components in decreasing order of sophistication and development, the knowledge base would come first, followed at a distance by student models, which in turn would be followed at a greater distance by the tutorial approach. This observation is not evident from Table 1, but it is hard to escape in reviewing these systems. This observation fairly well tracks the state of the art, particularly with regard to the device based simulation approach used in these intelligent tutoring systems. Significant progress has been made during the last several years in representing the knowledge required for expert systems. However, techniques to represent the processes used by human students to solve problems -- or fail to solve problems -- and techniques to deduce these processes from students' problem solving activities remain less well developed. Finally, the data free polemics that too frequently characterize our debates over instructional processes evince the rudimentary state of instructional science and the difficulty of applying it to computer based instruction.

Park, Perez, and Seidel (1987) corroborated this point when they concluded their review of intelligent tutoring systems by emphasizing that "the old problem of 'how to teach' still remains" (p. 39). As Park, et al. point out, our applications of intelligent tutoring systems have not resulted in any intellectual breakthroughs for learning or instruction. The contribution of intelligent tutoring systems research and development appears to lie mainly in the development of powerful computer systems that capture humans' learning and teaching processes. Like most innovations, intelligent tutoring systems may first have to be 'domesticated' and used to mimic what we already know and do before it will be free to evolve genuinely innovative approaches to instruction.

4. There is a fairly even distribution between rule-based and network-based approaches used to represent the subject matter knowledge bases for these systems. Four of the systems (TRIO, QUEST, SATS, and INCOFT) use rules, and five (SOPHIE, STEAMER, IMTS, CBMS, and MACH-III) use networks. The emphasis on operator and maintenance training using device based simulations does not seem to have forced developers into one or another approach for representing knowledge. The qualitative approach to modeling seems to find rules and networks equally useful. It may be notable that TRIO and INCOFT, which must minimize computational requirements in order to meet the real time requirements of their training objectives, both use rules. Generally, but not necessarily, rules place fewer computational requirements on systems, and they may be more appropriate when short time responses are at a premium in training. It may also be the case that when the subject matter is fairly well structured, as it is in these intelligent tutoring systems, which approach is chosen to represent the underlying knowledge base may not matter.

5. An overlay approach is used in all these systems to model student knowledge. Basically, student solutions to problems are 'overlaid' onto expert solutions, and mastery is inferred where the solutions match and no mastery is inferred where they do not. This appears to be a viable approach as far as it goes, but it may be insufficient for at least two reasons.

First, the knowledge structure of an expert may be not just absent in a student, but inappropriate as well. Intermediate stages of knowledge structuring may be needed by students, and leaping ahead to mastery knowledge in a few areas may inhibit development of mastery overall. This problem is recognized by IMTS, QUEST, and perhaps MACH-III all of which use hierarchies of knowledge representation, so that their knowledge base is not just an expert, but also several intermediate stages of expertise. Second, the knowledge structure does not account for student misconceptions. The problem of student misconceptions has been reviewed in the research literature on intelligent tutoring systems (e.g. Stevens, Collins, and Goldin, 1982) and in the development of intelligent tutoring systems such as BUGGY (Brown and Burton, 1978), but it remains very real perhaps because computers are finite state machines and as most teachers know, the possibilities for student misconceptions are infinite.

6. There are practically no data concerning the instructional effectiveness of these systems. Despite a smattering of pilot studies, informal observations, and anecdotal comments, none of the nine systems listed in Table 1 has been evaluated in a systematic manner. This state of affairs is characteristic of intelligent tutoring systems in general. An attempt was made to evaluate perhaps three of the 16 systems listed in the 1985 summary, and none of these resulted in reported data.

The lack of data may be due to differences in the culture of the research and development communities involved. Most intelligent tutoring systems have been produced by people who are interested in building systems. The development of one system inevitably produces more ideas for building the next. Developers view it almost as a matter of professional integrity not to dwell on any one development, but to pursue their ideas as well and as far as they can. It is not surprising that the issue of evaluation results in strong feelings and heated exchanges. Sooner or later, however, we must slow development enough to test these systems.

After about 15 years of developing intelligent tutoring systems, the clamor to determine if it 'works' is very hard to ignore. In the training world, 'works' usually means that a new functionality allows us to reduce costs without reducing effectiveness. Especially for people in the practical world who must decide whether or not to buy intelligent tutoring systems, costs must be taken into account (Orlansky, 1985). Sooner or later, the costs of developing, operating, and maintaining intelligent tutoring systems must be considered. For the moment, though, some data on effectiveness would go a long way toward satisfying the concerns of those (e.g. the military services) who are wondering where their research and development dollars went.

It is important to note that we do not need data just to show that these intelligent tutoring systems are successful (or not). We need data to increase the amount we learn from each of them. They are not easy nor inexpensive to build. We should wring as much data as possible from each one of them. In short, we need data to tell us if our systems are effective but also and perhaps more importantly, how they are effective. If we do not collect these data, a significant portion of intelligent tutoring systems development will be wasted.

7. These systems have received wide support from all three Services, and they have received a wide range of research and development funding. The Air Force supported development of two of these systems, the Army supported development of five systems, and the Navy supported development of six systems. Two of the systems were supported by both the Army and the Navy, and SOPHIE was supported by all three Services and the Defense Advanced Research Projects Agency.

Department of Defense research and development funding is graduated in specificity, ranging from basic research to prototype development. Basic research in training is largely funded by the Office of Naval Research, the Air Force Office of Scientific Research, and the Basic Research Office of the Army Research Institute. It is interesting to note how few of the systems discussed here were funded by basic research money. Most of these efforts were supported by 'exploratory development' and 'advanced development' funding provided by the Service laboratories and not by organizations set up to support defense related basic research in universities. It is notable that effectively none of these systems were developed in universities. They were developed by people and resources put into place to solve practical training problems for the military. The non-university, non-basic research support of these systems may indicate that they represent a technology that is coming of age.

SOME IMPRESSIONS

Based on the above review of intelligent tutoring systems and observations that may be made based on their development history, I have formed some impressions concerning the development of intelligent tutoring systems. These are only impressions. They appear to account for analyses completed thus far, but they can and will be changed in the light of contrary evidence. They are the following:

1. There are no intelligent tutoring systems.

This impression may be surprising given the topic of this paper. It could be discarded if we can find at least one system that contains the four basic elements of an intelligent tutoring system and that is sufficiently finished to be used by its intended students in the intended instructional setting. To date, however, there appears to be no such system. SOPHIE came close to meeting the system criteria and MACH-III may be even closer, but neither have been seriously used by students. BIP (Barr, Beard, and Atkinson, 1976) and Anderson's LISP and Geometry tutors (Anderson, Boyle, and Reiser, 1985) have been used by students in instructional settings, but they lack essential system components.

It may be that a true intelligent tutoring system is beyond the current state of our art. The problems to be solved by such a development are extremely difficult and poorly supported by substantive knowledge about the teaching/learning process. On the other hand, we do know how to build expert systems. There are about 1500 such systems now in existence. From a practical standpoint, we may have to be satisfied with efforts to apply expert systems to instruction and leave the development of what we have been calling intelligent tutoring systems to a later day.

2. Systematic research and development concerning intelligent tutoring systems is absent.

The literature on intelligent tutoring systems is almost entirely concerned with the fabrication, the building, of intelligent tutoring systems. Empirical evidence on whether they teach or how they teach is largely absent. The effort to develop intelligent tutoring systems seems like an effort to invent a horseless carriage without trying to drive any of the prototypes. Of course there is an empirical component in the intelligent tutoring systems area of development. One specifies behavior to be exhibited by a computer and then one tries to build a computer program that produces that behavior. This may in fact be a worthy area of endeavor, but it tells us little about the teaching/learning process. If the intent is to create a technology for teaching, then it is past time to see if any of these systems teach.

3. Our development of intelligent tutoring systems lacks scholarship.

To some extent it seems reasonable for inventors and developers to boldly go where their work leads them and not to concern themselves with what others have done or failed to do in the same area. To another extent, re-inventing the wheel, however cleverly accomplished is a waste of time. With a few exceptions, lack of knowledge about prior work in computer assisted instruction, findings from research in education and instructional psychology, and educational and psychological theory characterize the development of intelligent tutoring systems. Those familiar with instructional research are often struck by the re-discovery of familiar concepts and newly minted labels for long established ideas. It is always useful to learn what new eyes see as they peruse a familiar landscape, what significance they assign to its features, and what new perspectives they discover, but it is frustrating if it only serves to tell us what we already know.

Without empirical study and without scholarship, each venture into the intelligent tutoring systems world starts from scratch, and its findings return to the void. Without formative research of these systems involving empirical study of how they work, it is difficult to see what contribution they will make to our understanding of human learning and cognition. Impressively gifted and creative people have participated in this area of development. Perhaps we should expect more from them.

4. Intelligent tutoring systems remain the most promising area we have for achieving a genuine breakthrough in instruction.

The above impressions are complaints, but they are meant to be taken kindly. They are all concerned with how this development has been managed and "sold" -- not with any perceived weakness in the approach or its goals. The commendable concern with the underlying structures and incremental processes of human learning and cognition that is characteristic of the area should lead its practitioners to increasingly powerful forms of instruction -- if they will attend seriously to the primary, ostensible goals of the development.

The requirements for the capabilities promised by intelligent tutoring systems are not going to go away. The need for these capabilities can only be expected to increase. The computational techniques developed are genuine and continue to promise real opportunities for meeting these requirements. Whether or not the products of this development will achieve the goals we have set for intelligent tutoring systems remains to be seen, but there seems little reason to doubt either the significance of the effort nor the value of the outcome.

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